

USABC Energy Storage Testing High Power and PHEV Development

This presentation does not contain any proprietary or confidential information



Tim Murphy, Presenter

Manager, Energy Storage and Transportation Systems

Jeff Belt

Principal Investigator

DOE Vehicle Technologies Annual Merit Review

February 25, 2008

- Purpose
- Barriers
- Approach
- Technical Accomplishments
- Plans for Next Fiscal Year
- Summary
- Publications/Patents





Purpose

- **Support Vehicle Technologies, Hybrid Electric Systems/Energy Storage Technology Development by:**
 - Develop and validate the testing and analysis procedures used to track progress of program deliverables against DOE goals and objectives (technical targets).
 - Validation testing of United States Advanced Battery Consortium (USABC) deliverables in scheduled phases of the development projects (Batteries and Ultracapacitors).
 - Benchmark testing of non-USABC prototype devices of interest on a case by case basis.
 - Support the development of life prediction models for technologies of interest (Also part of the ATD presentations).
 - Maintain a flexible state-of-the-art energy storage test facility at the INL capable of supporting current and future development activities.
 - Closely coordinate these support activities with other national laboratories to maximize the value to development projects.
 - Primarily ANL for these activities

- **These tasks directly support technical barriers associated with the commercialization of both high power and high energy batteries.**
 - Cost
 - Validating series of deliverables aimed at lowering cost of materials and manufacturing etc.
 - Performance
 - Cycle types/life, low temperature power etc.
 - Abuse Tolerance
 - Unexpected failures or aggressive cycling during normal testing.
 - Life
 - Calendar, cycle, various combinations etc.



Approach

①

Testing

USABC and Other program deliverables

- Batteries
- Ultracapacitors

Cells, Modules, and Full Size Systems

Testing protocol is driven by customer needs (FreedomCAR, USABC, and others).

②

Analysis

Standards developed for data acquisition, analysis, quality, and management.

Data accuracy and uncertainty analysis.

Huge amounts of data are generated.

Software analysis tools have been developed (HPPCalc).

③

Modeling

Key tools are under development:

- Arrhenius Behavior
- Equivalent Circuit Models
- Life Prediction Models
- TLVT protocol
- Sigmoid Models

④

R&D (ATD)

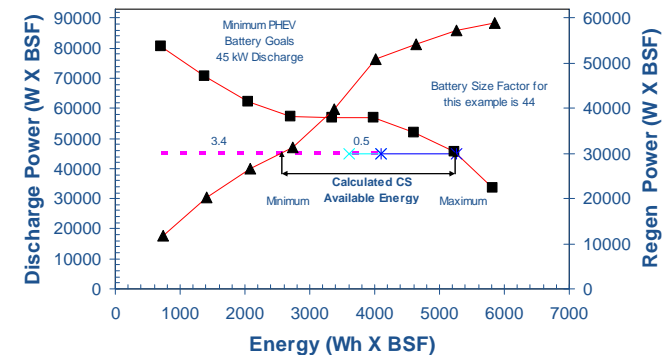
Applied research to explore basic issues of battery performance and aging.

- Specialized tests and measurements
- Coin Cell Testing
- Molecular-scale modeling



Technical Accomplishments/Results

- Developed and issued draft Plug-In Hybrid Electric Vehicle (PHEV) battery test procedures
 - Ref: “U.S. Department of Energy FreedomCAR & Vehicle Technologies Program, FreedomCAR Battery Test Manual For Plug-In Hybrid Electric Vehicles”
 - INL/EXT-07-12536, August 2007, Draft 2.
 - Validation and review ongoing in FY08
 - First version will be published 2Q FY08
 - Revision expected in FY09 or FY10
- Ongoing support to program participants for other test manuals:
 - FreedomCAR Battery Test Manual For Power-Assist HEV's
 - DOE/ID-11069
 - FreedomCAR Ultracapacitor Test Manual
 - DOE/NE-ID-11173





Technical Accomplishments/Results cont.

■ Testing of USABC Deliverables In FY2007/2008

- Johnson Controls – Saft, HEV Power Assist, Lithium-Ion
 - Completed long-term calendar life testing of FY1999 technology
 - 6 cell study, FY 2007 report delivered
 - Long-Term combined calendar/cycle life testing on FY2001 technology
 - 24 cell study, ongoing, quarterly and annual reports delivered
 - Completed cycle life/low temperature power testing on FY2005/06 technology
 - 6, 42 volt modules, final report pending
 - VL7P cell technology for calendar and cycle life testing, FY2006/07 technology
 - 32 cells, design process improvements for cost reduction, calendar life and low temperature performance.
 - Ongoing, quarterly and annual reports delivered



Technical Accomplishments/Results cont.

■ Testing of USABC Deliverables In FY2007/2008

- Enerdel, HEV Power Assist, Lithium-Ion
 - Calendar life study of new novel chemistry, FY2007 technology
 - 10 cells, Enerdel low cost electrode materials, ongoing
 - Quarterly and annual reports delivered
 - Calendar and cycle life testing of Argonne National Lab (ANL) anode technology delivered to Enerdel for cell construction and optimization.
 - 20 cells, ongoing, ANL developed low cost anode material
 - FY 2007 technology, quarterly and annual reports delivered
- Compact Power, HEV Power Assist, Lithium-Ion
 - Calendar life focused testing on FY2007 technology from large battery manufacturer, unique approach
 - 24 cells, ongoing, quarterly and annual reports delivered



Technical Accomplishments/Results cont.

- **Testing of USABC Deliverables In FY2007/2008**
 - Ultracapacitors, Carbon based double layer capacitors
 - Maxwell Technologies, FY2006 Technology
 - Performance and cycle life focused testing
 - 4, Gen-8, 48 volt modules
 - Completed 2007, report pending
 - NessCAP, FY2006/07 technology
 - Cycle and calendar life testing, energy density improvements
 - 14 cells in study aimed at improving energy and studying effects of temperature on performance.
 - Ongoing, quarterly and annual reports delivered



Technical Accomplishments/Results cont.

■ Benchmark Testing of Non-USABC Deliverables

- NLE (Japan) Power Assist, Lithium-Ion
 - Novel materials for cycle life and calendar life testing
 - 2, 48 volt modules
 - Cycle life testing completed, report delivered
 - Calendar life testing ongoing, quarterly and annual reports delivered

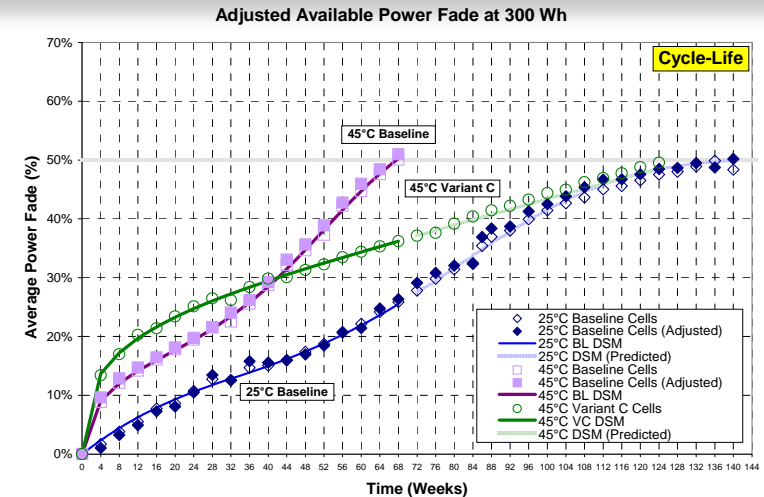


Activities for Next Fiscal Year

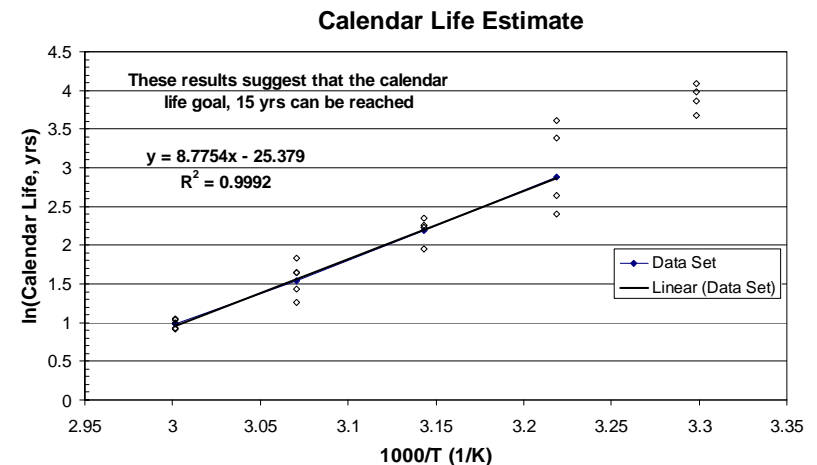
- Develop and validate the testing and analysis procedures used to status program deliverables against DOE goals and objectives (technical targets).
 - Continue to refine, modify, or add testing and analysis procedures to the PHEV Test Manual as user comments and issues are resolved. The lab testing is only now beginning and industry comments have not yet been received. A Manual revision is expected in the FY09 or FY10 timeframe.
 - Continue to support the HEV Power Assist and Ultracapacitor Test Procedures Manuals.
- Validation testing of USABC deliverables in scheduled phases of the development projects.
 - PHEV project deliverables expected from Compact Power first then from Enerdel and 3M. Cells first and eventually prototype vehicle packs are planned.
 - Provide test procedure and analysis support to A123 and Johnson Controls – Saft PHEV projects at ANL.
 - Continue the performance and life testing on deliverables under the HEV Power Assist projects from Johnson Controls – Saft, Compact Power, and Enerdel.
 - Complete testing of Ultracapacitors from the NessCAP project.

Activities for Next Fiscal Year cont.

- Continue to conduct benchmark type testing of non-USABC prototype devices of interest on a case by case basis.
 - Novel chemistries from Japan, others
 - Ultracapacitors
- Continue to support the development of life prediction models for technologies of interest.
 - As empirical models become more robust and true physical models emerge, accelerated testing becomes more accurate and efficient.
 - Arrhenius Methods
 - TLVT methodology
 - Double Sigmoid (DSM) approaches
 - Others



Average power fade vs. time for DOE-ATD Li-ion cells for test data (symbols) and predictions made by the DSM model (curves). The “adjusted” notation refers to data adjusted to true test temperature.





Summary

- **Advanced batteries that meet or exceed DOE Vehicle Technologies Program goals and objectives will have a significant effect on vehicle fuel use nationally.**
 - Testing is critical to the success of this effort.
- **Our approach to this activity is under constant review and is improved or modified annually as needs change.**
 - Targets, Procedures, Analysis tools, Models etc.
- **Data quality is critical to the decision points for these projects**
 - Uncertainty and accuracy measurements have been used.
 - Close coordination with suppliers help resolve questions.
 - Issues can and do effect decision schedules.
- **Technology Transfer occurs due to direct collaboration between DOE, suppliers, automobile industry, and the test facilities.**
- **FY08 – continue to improve and advance testing/analysis capability.**



Publications, Presentations, Patents

■ FY 2007 Publications

- Christophersen, J.P., Hunt, G. L., Ho., C. D., Howell, D., "IPulse resistance effects due to charging or discharging of high-power lithium-ion cells: A path dependence study,," *J. Power Sources*, (accepted) 2007.
- Abraham, D.P., Knuth, , J. L., Dees, D. W., Bloom, I. and Christophersen, J.P. "Performance Degradation of High Power Lithium-Ion Cells – Electrochemistry of Harvested Electrodes," *J. Power Sources*, (submitted) 2007.
- Belt, J.R. "FreedomCAR Battery Test Manual For Plug-In Hybrid Electric Vehicles." Draft 2, INL/EXT-07-12536, August 2007.

■ FY 2007 Presentations

- J. P. Christophersen, G. L. Hunt, I. Bloom, E. Thomas, and V. Battaglia, "Battery Technology Life Verification Testing and Analysis," Proceedings from the *23rd Electric Vehicle Symposium*, (submitted).
- Saha, B., Goebel, K., Poll, S., Christophersen, J., "An Integrated Approach to Battery Health Monitoring using Bayesian Regression, Classification and State Estimation," Proceedings from the IEEE AUTOTESTCON 2007, in press.
- Christophersen, J. P., Morrison, J. L. Morrison, Schubert, B. J. and Allred, S. "Implementation and Validation of Uncertainty Analysis of Available Energy and Available Power," Proceedings from the *53rd International Instrumentation Symposium*, 2007.
- Luther, T. A.; Harrup, M. K.; McNally, J. S.; Gering, K. L.; Jamison, D. K. "Cyclotriphosphazene Derivatives as Liquid Electrolytes for Lithium-ion Batteries," 234th National Meeting of the American Chemical Society, Boston, MA, August 2007.



Publications, Presentations, Patents cont.

■ FY 2007 Presentations cont.

- Luther, T. A.; Harrup, M. K.; McNally, J. S.; Gering, K. L.; Jamison, D. K. "Synthesis and Characterization of Cyclotriphosphazene Derivatives as Liquid Electrolytes for Lithium-ion Batteries," 62nd Northwest Regional Meeting of the American Chemical Society, Boise, ID, June 2007.
- J. R. Belt., C. D. Ho, "Path Dependence for Calendar and Cycle Life Testing," Advanced Automotive Battery Conference, May 2007.
- Gering, K.L. "Electrolytes at Equilibrium: Accurate Prediction of Key Thermodynamic, Transport, and Ion Solvation Quantities", 2006 AIChE Annual Meeting, San Francisco, CA, November 2006. INL/CON-06-11919
- Belt, J.R., "Plug-In Hybrid Electric Vehicle Battery Testing Procedures", Proceedings, 23rd Electric Vehicle Symposium.

■ FY 2007 Reports

- Belt, J.R., "FreedomCAR Hybrid Vehicle Battery Development: Energy Storage Testing and Analysis Interim Report for NEC Lamion Energy, Ltd Modules," INL/EXT-07-13227, September 2007
- Belt, J.R., "FreedomCAR Hybrid Vehicle Battery Development: Energy Storage Testing and Analysis Final Report for Saft HP-12 Calendar Life Cells ," INL/EXT-07-13226, September 2007
- Belt, J.R., Motloch, C. G., Murphy, T. C, "FreedomCAR Hybrid Vehicle Battery and Ultracapacitor Development: INL FY 2006 Energy Storage Testing and Analysis Summary Report," INL-EXT-07-12215, November 2006



Publications, Presentations, Patents cont.

■ Patents

- Patent 7,147,071 “Thermal Management Systems and Methods”, Gering K.L., Haefner, D.R., December 12, 2006.

■ Invention Disclosures (Patent Applications)

- IDR 1297 - Jamison, D.K., “Measurement Method for Battery Management System, submitted 6/14/07.
- IDR/Docket #BA-259 - Christophersen, J. P., Motloch, C., Murphy, T.C. “Methodology for Real Time Battery State-of-Health Estimations,” submitted 5/9/2007.